

# Ultras TPV Conversion Efficiencies Depending on the Energy Gap of the Materials Used and The Source Emission Temperature

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**Abstract** — The Interest on thermophotovoltaic cells (TPV) is their ability to generate electricity from heat sources. They are made of semiconductor materials which are classified according to the width of their band gap. Those with smaller band gaps, so capable of absorbing large wavelength radiation such as infrared, offer better prospects for greater extension of solar energy, especially in hot countries. This article is a study of the ultras TPV conversion efficiencies depending on the energy gap of the materials used and the source emission temperature. This study focused generally on the cells at high, medium and low band gap.

**Keyword** — Thermophotovoltaic, cells, efficiency, material, power output, band-gap, emitter, filter.

## 1. INTRODUCTION

The technology of thermophotovoltaic (TPV) devices will develop a pathway that may be an alternative to fossil energy, as it allows the generation of electricity from thermal energy. This technology was born in the context of the cold War between the United States and Russia. [1] Many researches have concluded that their efficiencies are much higher than those of photovoltaic cells.

## 2. COMPONENTS OF A TPV DEVICE

A thermo photovoltaic device consists of a heat source, an emitter, an optical filter and suitable photovoltaic cell as shown in Figure 1.

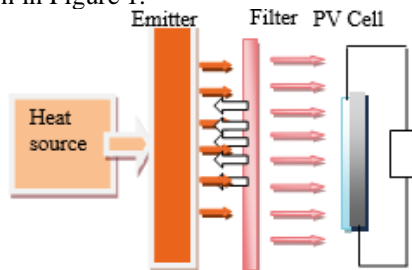


Figure 1: Schematic diagram of a thermal photovoltaic device.

The heat generated may come from solar radiation, from the combustion of a gas and nuclear reaction. The crucial element of a TPV generator is the emitter. The adaptation of the emission spectrum with the spectral

sensitivity of the cell is the major difficulty encountered in the optimal operation of the generator. Bitnar [2] studied the selective emitters based on rare earths. The several types of emitters have emerged.

Filter, placed just after the emitter is operable to select the wavelength of the emission spectrum from the emitter. It allows to increase the efficiency of the TPV cell and reduce the harmful effects of heat on the cell.

The TPV cell plays a key role in the conversion of electromagnetic radiation into electricity. The optimization of these materials with infrared radiation is the major task for satisfactory conversion efficiencies. The materials can be divided into three categories [3] big gap, medium-band gap materials, [4], [5] and low-band gap materials. [6], [7], [8].

## 3. RESULTS AND DISCUSSION

- *Power delivered by the issuer*
  - *In the case of black body*

The Planck function reflects the radiation emitted by a black body. It is a function of the temperature and wavelength [1].

$$P(u, T) = \xi \cdot T^3 \cdot \frac{u^3}{e^u - 1} \quad (1)$$

$$\xi = \frac{2\pi k^3}{(c \cdot h)^2} \quad (2)$$

$$u = \frac{E}{K_B} \quad (3)$$

K is the Boltzmann constant, h is Planck's constant, C is the speed of light, and T the source of the emission temperature and frequency.

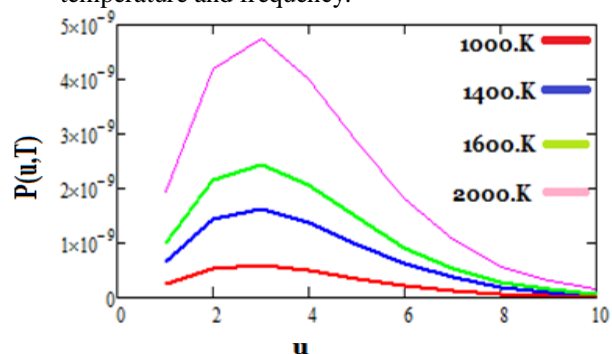


Figure 2: Power emitted by the emitter according to (u,T) which is also a function of the frequency.

▪ **In the case of a gray body**

For a gray body, the radiation power per unit area per unit photon energy (eV) is:

$$P_{rad}(E, T) = \varepsilon(u)P(E, T) \quad (4)$$

$\varepsilon(E)$  is the emissivity of the radiator.

• **Performance of the emitter**

$$\eta_E = \left\{ 1 + \gamma \left[ b e^{-\frac{u_E}{T_E}} \left[ 6 + 6a_1 \frac{E}{T_E} + 3a_2 \left( \frac{E}{T_E} \right)^2 + a_3 \left( \frac{E}{T_E} \right)^3 \right]^{-1} \right] - 1 \right\}^{-1} \quad (5)$$

$$(b = \frac{15}{\pi^4}, a_1 = \frac{1}{k_B}, a_2 = \frac{1}{k_B^2}, a_3 = \frac{1}{k_B^3}, \gamma = \frac{\varepsilon_l}{\varepsilon_b})$$

$K_B = 1.38 \cdot 10^{-23}$ , Boltzmann constant,  $\varepsilon_l$  and  $\varepsilon_b$  variables.

By posing,  $u_E = E/kT_E$  we were able to trace the curve below,  $T_E$  is the temperature received by the emitter.  $\varepsilon_{El}$ , emittance for the low-energy photon region of the spectrum that can not be converted into electricity, and the emittance,  $\varepsilon_{Eb}$ , for the energy of the photons useful spectrum region.

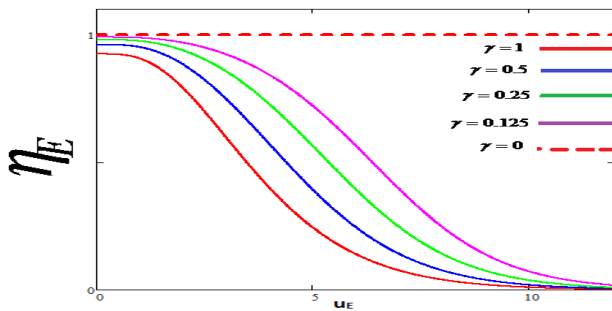


Figure 3: Performance of the emitter based on  $u_E$  and  $\gamma$ .

It is clearly seen that  $\eta_E$  essentially depends on  $\gamma$ . The proof is, when its value is zero  $\eta_E$  reaches its maximum and remains constant regardless.  $u_E$  this means that after all the radiation from the source reaches through the emitter without loss. However, when it is not zero, then the curve has two concavities. The first concavity occurs just after an almost constant shape of the curve. At this moment all the photons have a minimum value of  $u_E$  between 1.5 and 2.5 but of these values, the energies of photons are low and their densities decrease abruptly. Beyond the second concavity, the photon energy is almost zero and tends to zero. In those cases where the curve is not constant, the ideal would be to recover all the photons having the minimum energy also depends on  $\gamma$ .

• **Efficiency thermo photovoltaic cells**

The overall performance of TPV device is obtained from the parameters related to the emitter, the filter and the PV cell.

$$\eta = \frac{P_{el}}{Q_{th}} \quad (6)$$

The calculations are developed in [1]. The electrical power must be calculated from the potential  $V$  and the current density  $J$  developed by the cell. Developments have given the following relationship:

$$P_{el} = \frac{A_c}{\lambda_g} \int_0^{\lambda_g} (1 - \rho_c) q_{ic} P(\lambda) d\lambda \quad (7)$$

$\lambda_g$  is the length corresponding to the band gap of the PV cell material,  $A_c$  is the cell surface,  $q_{ic}$ : the flow of radiation incident on the PV cell per wavelength unit.  $\rho_c$  the reflectance of the emitter and of the cell respectively.  $P(\lambda)$  is the body of the emission power Black constituted by the emitter. The maximum electric power is:

$$P_{el\max} = \frac{A_c}{\lambda_g} \int_0^{\lambda_g} (1 - \rho_c) q_{ic} \lambda d\lambda \quad (8)$$

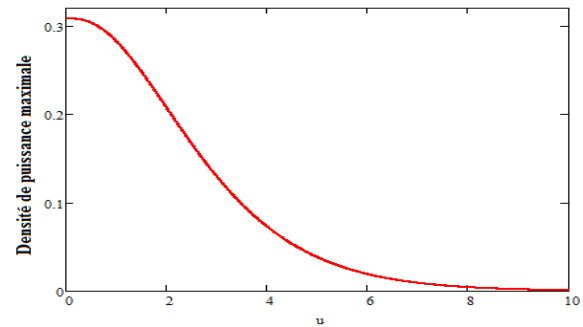


Figure 5: maximum power density as a function of  $u$

The determination of incident thermal power  $Q_{th}$  requires to assume that all incidents and outgoing flows of energy are uniform.

$$Q_{th} = A_E \int_0^{\infty} (q_{0E} - q_{iE}) d\lambda \quad (9)$$

$q_{0E}$ : Flux of the radiation emitted by the transmitter unit by wavelength.

• **Efficiency versus  $E_g$  for different temperatures**

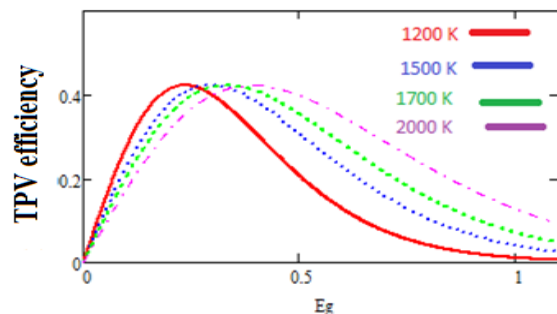


Figure 6: TPV efficiency function of  $E_g$  (eV) for different temperatures.

The curves have the same shape and have the same maximum value. This maximum yield moves toward the low values of  $E_g$  for low temperatures. However, they are less constricted to high temperatures.

- **Maximum TPV efficiency vs emitter performance**  
 R [1] describes the emitter's performance and he's also the ratio of the emittance, for the region of low photon energy the spectrum that cannot be converted into electricity, and emittance, to useful energy photon the region of the spectrum.

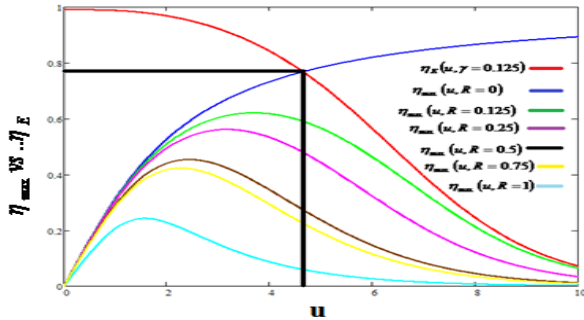


Figure 7: TPV maximum performance and efficiency of the emitter according to  $u$ .

The figure reflects two developments all depend on the energy of the gap. The red curve reflects the performance of a transmitter.

In this case,  $T_E$  is the temperature issued by the transmitter and is the corresponding wavelength. We see that the returns are students who have low and the other curves reflect TPV conversion efficiency, function  $u = u_g$ , ( $u_g = E_g / kT_E$ ). The ideal would be to have an extremely low  $R$  value, the zero limit, to expect a student conversion efficiency. With the set parameters of our analysis, the graph shows a very remarkable point: the encounter between the red and blue curve. The maximum conversion efficiency is not adequate to the maximum performance of the issuer. All times, the conversion efficiency is acceptable as  $u = u_g$  that corresponds with this point. The photons from the transmitter with an energy that matches  $u_g$  will be well absorbed by the PV cell. Those which are lower will warm up the device that would eventually deteriorated. For other photons, their excess energy would have the same effects as those which are lower.

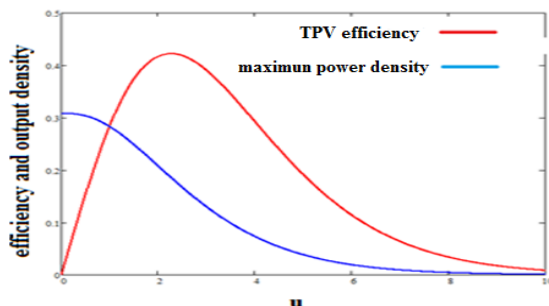


Figure 8: TPV efficiency and maximum power density as a function of  $u$ .

- **Performance of the cells to high gap**

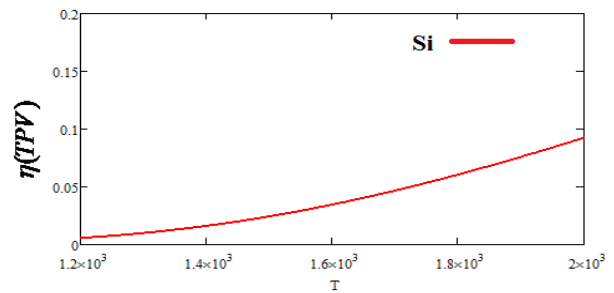


Figure 9: efficiency the TPV in the function of temperature (K) of the emitter to a silicon-based cell.

The performance is extremely low. This means that silicon is a poor candidate for the TPV industry.

- **Performance of the cells in the medium gap**

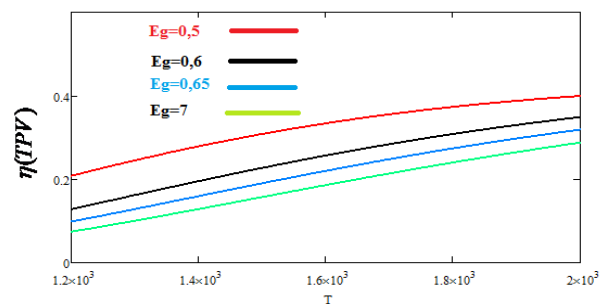


Figure 10: efficiency the TPV in the function of temperature (K) for the cells in gap (eV)

There has been a net increase in the efficient with the temperature and with  $E_g$ . The different materials are: GaSb, Ge, InGaAs, and InGaAsP.

- **Cell efficiency small-gap**

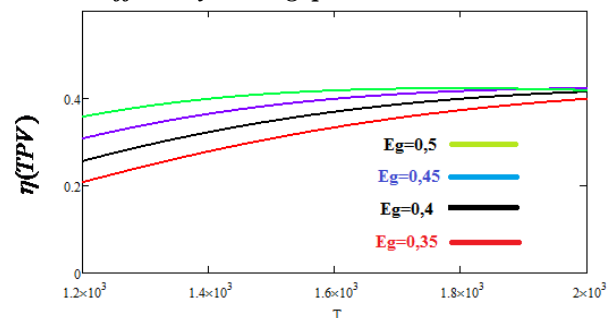


Figure 11: efficiency the TPV in the function of temperature (K) for the cells in gap (eV) low.

The best efficiencies are obtained with the small-gap cells. The search for the best efficiencies of TPV cells should focus largely on small-gap materials. Such as InGaAsSb, InPaSb, InPaSP, GaInAsSb, GaInAsPSb

... All curves gave a maximum efficient slightly higher than 40%. This proves once again that the TPV industry is an excellent candidate to replace fossil energy.

## 5. CONCLUSION

The thermophotovoltaic (TPV) devices potentially have a greater return than photovoltaic cells. But that performance depends on many factors; the emitter, the filter with low absorptivity in some cases can affect proper operation of the cell because the gap of the cell material should be compatible with the radiation spectrum. On the other hand, there are not many materials with very low bandgap, which requires very high temperatures emitters. We studied the maximum return that can be expected of TPV cells according to the incident temperature and gap of the material. We made a comparison between the performance of low-cells, medium and large gap that requires low transmission temperatures. Any time small-gap cells offer better performance. The degree of emission is important because some degree are not resistible by materials and are detrimental to the performance and durability of the unit. Most current research is focused on the manufacture of several types TPV cells ranging ternary cells which are small-gap cells.

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